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REPORT NO. RN-S-0308
TO
AEC - NASA SPACE NUCLEAR PROPULSION OFFICE

ETS-1 DATA ACQUISITION SYSTEM
ACCURACY TEST SPECIFICATION

JULY 1966

NERVA PROGRAM

CONTRACT SNP-1

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**AEROJET
GENERAL**

REPORT NO. RN-S-0308

**ETS-1 DATA ACQUISITION SYSTEM
ACCURACY TEST SPECIFICATION**

JULY 1966

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM

CONTRACT SNP-1

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ETS-1 DATA ACQUISITION SYSTEM

ACCURACY TEST SPECIFICATION

To enable meaningful and efficient collection of test data, at least one mode will be tested as early in the program as possible. The results of the preliminary test will be utilized to establish the primary test requirements such as the sample size, test levels, optimum test conditions, procedures and analysis for each mode to best achieve the estimation of modal accuracy.

2.0 SCOPE

The diagnostic portion of the ETS-1 Data Acquisition System will include engine diagnostic channels, digital data subsystems, and analog recorders as depicted by Figure 1.

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3.0 OBJECTIVES

The objectives of the test program described herein shall have two classifications, primary and secondary. The primary objective is concerned with the basic goal of the program of ascertaining the accuracy of the ETS-1 Data Acquisition System. The secondary objectives are concerned with the gathering of additional data to obtain estimates of performance parameters or to have data available for future studies that may be desired. This is assuming that certain contingencies or abnormalities are observed during the assessment of the accuracy of the ETS-1 data system. The primary objective will not be compromised for the secondary objectives.

3.1 Primary

The accuracy values, as defined in Section 1.0, for the ETS-1 Data Acquisition System will be determined for each mode of operation that is anticipated for the ETS-1 test program. The accuracy values for each mode will include:

- (a) Mean error (bias), % of full scale
- (b) Estimate of random variation (noise), % of full scale
- (c) Ninety-nine percent confidence interval such that 99.9% of the data points will fall within the boundaries of the error indicated.

The philosophy inherent in the statistical design and subsequent data analysis is to obtain maximum useful information to describe the accuracy objectives.

3.2 Secondary

The secondary objectives are designed to provide supporting data which are valid and applicable to an overall analysis of the ETS-1 Data Acquisition System. The secondary objectives will not be accomplished unless system abnormalities are indicated in the data analysis of the primary objectives. The required

analyses are not within the scope of the current program. Data will be available from the primary tests for the evaluation of drift, linearity, subsystem variability, and channel-to-channel variability. Additional tests will be conducted to permit the evaluation of other system parameters such as ac and dc crosstalk, frequency response, aligning, and calibration accuracy as specified under Section 5.3, below.

4.0 PROGRAM PHASES

4.1 Phase I - Test Plan

The test specification presented herein describes the purposes, criteria, and type of data and analysis required to derive the accuracy objectives in the most economical, timely, and expedient manner.

4.2 Phase II - Preparation of Test Procedure

A set of test procedures shall be prepared by NTO to conduct the tests specified in Section 5 of this test specification and shall be submitted to REON for an integrated (REON/WANL) review prior to the initiation of testing.

4.3 Phase III - Program Verification

4.3.1 Preliminary Tests - Preliminary tests shall be conducted on twenty (20) 4-arm standard strain gage channels. The modes to be studied will be tested with two subsystems, each subsystem tested with ten channels. Each of the twenty (20) channels will be tested at four levels of input (0%, 25%, 50%, 75%) and each input level tested for five time increments (0, 0-2, 0-4, 0-8, 0-12 hours). Sixty four (64) observations will be taken for each test condition. The modes of operation for this test shall be 3 + 4 + 5 + 8 and 7 + 8, (Figure 2). These channels shall be tested as specified by the accepted test procedures.

4.3.2 Data Reduction - The preliminary test data shall be reduced as described in Appendix A of this test specification.

4.3.3 Data Analysis - The preliminary test data shall be analyzed as described in Appendix C of this test specification. The analysis will entail studying the variation pattern of each of the test factors or combination of test factors (noise, channel-to-channel variability, linearity, drift, and subsystem differences); thus arriving at test requirements that enable the ETS-1 accuracy objectives to be achieved with a minimum number of tests and expense of deriving equivalent accuracy estimates in the other modes to be tested.

4.3.4 Test Specification/Test Procedure Addendum - After the preliminary data have been analyzed and a Preliminary Test Report issued, the data results may necessitate the modification to this test specification and the test procedures. The number and types of tests may be modified with the knowledge gained from the preliminary test program.

4.4 Phase IV - Performance of Tests

NTO shall perform tests according to the accepted procedures. REON and WANL personnel may witness the tests and shall be responsible for reviewing any departures from the procedures that are made prior to testing.

4.5 Phase V - Test Data Report

The data tapes shall be processed by NTO, converted to engineering units as detailed in Appendix A, and will be reported with other testing details in accordance with Section 5.8 of this Test Specification.

4.6 Phase VI - Data Analysis

The test data and supplementary information detailed per Section 5.8 shall be analyzed by REON as described in Section 6 of this Test Specification.

4.7 Phase VII - Performance Evaluation Report

Following the completion of the data analysis, REON shall issue an Analysis Report. This report shall contain, as minimal information, the data specified in Section 7. The final analysis report shall be reviewed by NTO and WANL prior to issuance.

5.0 TESTING

5.1 System Description

The complete system under evaluation is shown in Figure 1. This consists of the transducer signal conditioners, two digital data acquisition subsystems, cables, patch boards, termination boxes, tape transports, strip chart recorders, FM tape recorders, and optical oscillographic recorders. The operational modes to be used in this evaluation are shown in Figures 2 through 7.

5.2 Pretest Requirements

The appropriate Data Acquisition System components shall have been calibrated and/or reinspected per standard NTO procedures. Pretest preparations shall be performed in accordance with normal NTO pretest operating procedures documented per Section 5.6.

5.3 Types of Tests

The following tests shall be conducted to produce the data necessary to evaluate the system performance. Each mode shall be tested in accordance with Table I (as modified by the results of the preliminary testing). From this evaluation, system accuracy can be determined. A signal will be introduced with a transducer simulator or transducer which shall be used as the source of the reference signal. These transducer simulators or transducers shall be connected as near to the engine-facility interface as is possible and practical at the time the test program is performed. Channels to be tested shall be selected at random. The test program for each mode is described by Table I.

5.3.1 Channel Calibration - Each channel shall be calibrated per Table II schedule and in accordance with normal NTO pretest setup procedures. The 0, 25, 50, 75 and (when applicable) 100% calibration steps shall be made. These calibration procedures shall be compatible with Appendix "A" requirements and shall be documented in accordance with Section 5.6.

5.3.2 End-to-End System Accuracy Test - Finite input signals will be provided to the test channels from the simulators and transducers and the system output signals shall be recorded on tape and other records as indicated in Table I.

5.3.3 Drift Tests - After channel calibration, per Paragraph 5.3.1, the system shall not be adjusted until the drift test is completed. The tests described in Paragraph 5.3.2 shall be repeated at 2, 4, 8 and 12 hours. The environmental temperatures at the simulators, signal conditioners, and digital subsystem shall be recorded at the start of each test interval.

5.3.4 DC Crosstalk - This test shall be conducted to evaluate the coupling between all channels when a dc signal is impressed on a selected few channels. Two stimulated channels shall not be adjacent. This test shall be conducted utilizing two (2) modes: a low-level configuration 10 samples per second, a high-level (100 S/S) through a narrow band amplifier configuration. Any signal detected on unstimulated channels adjacent to a stimulated channel shall be designated as dc crosstalk.

5.3.5 Frequency Response - The upper frequency response of the wide band system will be determined by injecting a constant amplitude sine wave function into the system input, varying the frequency of this signal from 1 cps to 100 KC and recording this signal on wide band magnetic tape and oscillograph recorders. Three hundred fifty ohm strain gage mode 3+4+5+8. Figure 2 shall be used. Galvanometers for the oscillographs will be selected to coincide with the anticipated XE-Engine transient measurement requirement.

5.3.6 AC Crosstalk - The channels selected to be evaluated for ac crosstalk shall be tested for the coupling effect of ac signals. The unused channels adjacent to the simulated channels shall be recorded, and any resulting data on the unused channels shall be considered to be ac crosstalk.

5.3.7 Aliasing - A test will be designed to determine the signal deterioration and distortion caused by subjecting the system to signal frequencies that will sweep through the fold-over frequency for the multiplexer sampling rate.

The distortion in the signal as the input frequency approaches and surpasses the fold-over frequency is known as aliasing. The test will also determine the extent of aliasing caused by inherent system noise signals. System aliasing caused by signal frequency will be determined by injecting 0.5 cps to 500 cps constant amplitude sine wave signals into the input of the channels set up in recording the data aliasing test mode discrete frequencies. System aliasing in the 10 S/S digital channels caused by inherent 60 cps system noise signals will be determined by injecting a known dc signal with a simulator and recording the output signals simultaneously on an unfiltered 10 S/S channel and a filtered 50 cps or 100 cps channel.

5.4 Test Equipment

5.4.1 Simulators - The following types of simulators and transducers will be required to simulate the transducers to be connected to the type channels under test. See Appendix "B" for simulator and transducer description.

- 5.4.1.1 Thermocouple, C/A, C/C, W/WRe, WRe/WRe
- 5.4.1.2 Strain gage, 350, 120 and 60 ohm 4-arm bridge
- 5.4.1.3 Strain gage, 120 ohm 2-arm bridge completion
- 5.4.1.4 Resistance temperature bridge
- 5.4.1.5 Swept potentiometer
- 5.4.1.6 Analog voltage

The above types of simulators shall have their accuracy traceable to the National Bureau of Standards. The simulators shall have multiple ranges and multiple outputs and shall be consistent with the design schematics in Appendix B of this test specification.

5.4.2 Other Test Equipment - All other test equipment used shall have been calibrated within 60 days or less prior to use; the time interval between calibration and test shall be as short as practical.

5.5 Modes of Operation

The ETS-1 Data Acquisition Test Program shall be applicable to the modes of operation anticipated during normal test usage. The modes are distributed among the transducer types as shown in Table I and Figures 3 through 7.

5.6 Test Procedures

The test procedure shall specify how each test shall be performed consistent with this specification. The test conditions shall be outlined in detail; sample data sheets shall be included in the test procedures.

5.7 Test Conditions

All tests shall be conducted under the specified environment of conditions of the Data Acquisition System Specifications. Other operations at ETS-1 which typify normal testing operations shall be continued as a normal environmental condition. Sufficient data shall be supplied to indicate any environmental conditions which could affect the test results. The condition of all unused channels during each test period shall be documented per Paragraph 5.8.

5.8 Test Data Report

Following completion of the tests specified by this Test Specification, a Test Report shall be issued for use in evaluating the data acquisition system. This report shall contain, as minimal information, the data specified herein.

5.8.1 Test Setup Description - The Test Report shall include a brief description of each test setup. Detailed test setup data sheets shall be appended to the report.

5.8.2 Test Procedure - The complete test procedure shall be attached as an appendix to the Test Report. Any deviation from the test procedures test setup or maintenance or abnormal testing conditions shall be reported.

5.8.3 Test Equipment - Simulator data, including a schematic diagram, shall be included in the report to indicate the accuracy and traceability to the National Bureau of Standards of each simulator. A complete description of all other test equipment shall also be included.

5.8.4 Test Results - The complete digital data obtained shall be converted to engineering units as specified in Appendix A and included in the report. A description of the tape format shall be provided. Copies of raw data, calibration corrected and engineering unit data tapes together with copies of all analog and strip chart data and other test records, shall be supplied to REON with the Test Report for analysis and evaluation. Data shall be annotated to indicate any known causes of data error or conditions that may have influenced the test results.

5.8.5 Recommendations - Any recommendations for improving the operations, procedures, and/or equipments associated with the data acquisition system shall be provided.

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6.0 DATA ANALYSIS

6.1 General

The accuracy of the ETS-1 Data Acquisition System, as defined in Section 1.0, will be determined for each mode of operation that is anticipated for the ETS-1 test program. The accuracy value for each mode will include the mean error (bias), an estimate of random variation (noise) and a 99% confidence interval such that 99.9% of the data points will fall within the boundaries of error indicated.

6.2 Primary Objective

The test data shall be analyzed to determine the data acquisition system accuracy for each mode of operation as follows:

6.2.1 System Bias - The system bias value represents the index that describes how the output signal differs, on the average, from a given input signal. The bias values shall be determined by computing the average of the deviations of the individual output observations from the simulated input signal. The system bias, $\bar{X}$, is then defined as

$$\bar{X} = \sum_{i=1}^t \frac{(X_i - N)}{t}$$

where X_i is the i th of t signal output observations for a given mode of an input signal of N .

6.2.2 Signal Noise - Signal noise represents the amount of variation of the output signal observations about the system bias value ($\bar{X}$) and is a measure of the repeatability or precision that may be expected from a given signal input. Signal noise, S , shall be determined by obtaining a root mean square of the deviation about the bias value obtained under Paragraph 6.2.1. This may be expressed as the following equation:

$$S = \sqrt{\sum_{i=1}^t \frac{[(X_i - N) - \bar{X}]^2}{t - 1}}$$

6.2.3 Confidence Interval - The confidence interval identifies the degree of confidence of the estimated accuracy of the system. That is, an interval will be stated that will include 99.9% of the observed output values of each mode of operation and that will assure 99% confidence that this interval is correct. This shall be accomplished by obtaining estimates of the bias ($\bar{X}$) and noise (S) as shown above and selecting a value of K, which is a function of sample size, that will assure the desired confidence interval. The confidence interval is expressed by the relationship:

$$\text{Confidence interval} = \bar{X} \pm KS$$

Initial test data will be utilized to evaluate the required value of K and the sample size for the balance of the testing. The sample size will be adjusted as required to obtain this value. Further details of the analysis of the initial test data and utilization of the analytical data are presented in Appendix C.

6.3 Secondary Objectives

The data collected during the secondary objective testing will be evaluated with the primary objective data to define further the ETS-1 Data Acquisition System characteristics, providing the primary objective analysis establishes a requirement for further evaluation.

6.3.1 AC Crosstalk - The data collected in accordance with Paragraph 5.3.6 shall be evaluated as specified in Appendix C to determine the coupling effects of ac signals.

6.3.2 DC Crosstalk - The data collected in accordance with Paragraph 5.3.4 shall be evaluated as specified in Appendix C to determine the coupling effects of dc signals.

6.3.3 Frequency Response - The data collected in accordance with Paragraph 5.3.5 will be evaluated in accordance with Appendix C to determine the upper - 3db point and system roll-off characteristics.

6.3.4 Calibration Analysis - The data collected in accordance with Paragraphs 5.3.1 and 5.3.2 will be evaluated in accordance with Appendix C to assess the estimate of noise as compared to the simulated signal.

6.3.5 Drift - The data collected in accordance with Paragraph 5.3.3 shall be evaluated to assess the effects of drift on system accuracy.

6.3.6 Aliasing - The data collected in accordance with Paragraph 5.3.7 shall be evaluated to assess the effects of aliasing on system accuracy.

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7.0 PERFORMANCE EVALUATION REPORT (ANALYSIS REPORT)

A Performance Evaluation Report shall be issued by REON following completion of the test data analysis. This report shall contain the following information as a minimum:

7.1 Test Objectives

A discussion of the test objectives and a brief description of the tests conducted shall be included in the Analysis Report.

7.2 Analytical Procedures

The Analysis Report shall include a brief description of the analytical procedures utilized in the evaluation of the test data.

7.3 Preliminary Test Analysis

A discussion of the preliminary test analysis shall be included. This discussion shall report the results of the analysis and the test plan modifications resulting from the preliminary test and analysis.

7.4 Statement of Accuracy

The Analysis Report shall include a statement of accuracy for each type channel and a confidence interval for this statement of accuracy. Also, statements of evaluation shall be included relative to each secondary objective of the test program if necessary. Test and analyzed data shall be appended to the report as required to support the conclusions of the test and analysis program.

7.5 Test Adequacy

A discussion of the adequacy of the test and analysis shall be included in the report. This discussion shall include test and analysis limitations,

known causes of test data error, unknown causes of test data errors and anomalies, methods of improving testing and analysis, and requirements for additional testing.

7.6 Recommendations

The report shall include recommendations for improving operations, procedures and equipment, and testing and analysis techniques as appropriate.

8.0 DEFINITIONS

8.1 Confidence Interval

Degree of assurance that interval will contain the true population parameter (for the accuracy analysis that parameter is the mean error and 99.9% of the observed values).

8.2 Mode

Routing of an input signal through a unique set of classes of components, i.e., transducer, terminal box, signal conditioner, **patch board** amplifier, filter, digitizer, recorder.

8.3 Channel

Routing of a signal on a specific set of components in a mode, e.g., component type or model number remains the same, only the serial number of the component changes.

8.4 Subsystem

A digital data subsystem containing the amplifiers, multiplexers, digitizers, low pass filter, and formatters.

8.5 Level

Test level of the input signal represented as 0%, 25%, 50%, 75%, and 100% if applicable.

8.6 Noise

Noise (precision) is the variation about the observed mean error for a given period, for a particular channel and mode.

8.7 Test

A sequence of signals from a given input level, test time increment, and channel at a particular mode of operation.

8.8 Observation

A recorded output for a test.

8.9 Bias

The deviation of the observed mean from a true input value.

8.10 Variance

Measure of the variation defined as the root mean square of the deviations from the observed mean or

$$\sigma^2 = \sum \frac{(X - \bar{X})^2}{N}$$

8.11 Unbiased Estimate of Variance

Estimate of the population variance defined as

$$s^2 = \sum \frac{(X - \bar{X})^2}{N - 1}$$

8.12 Standard Deviation

The square root of the variance.

8.13 Mean

The sum of the observations divided by the number of observations summed (average).

8.14 Accuracy

Difference in known input on recorded output measured in terms of a 99% confidence interval such that 99.9% of the data points fall within the boundaries indicated.

8.15 Drift

Deviation of a signal from a standard because of an elapse of time or environmental change.

8.16 Linearity

The maximum absolute differences ($X_1 - \bar{X}$) at the various input levels, where X_1 is the input value and $\bar{X}$ is the measured average output value.

8.17 Traceability

The calibration of an instrument is said to be traceable when all of the significant accuracy-determining elements in the design, individually and in that particular configuration, are compatible with the accuracy levels at which they are to be verified by comparison with accepted standards.

8.18 Precision

Degree of reproducibility among several independent measurements of the same true value under specified conditions.

8.19 Simulator

A device which is capable of generating a voltage or signal to replace the output of a physical transducer or sensor which measures a physical parameter.

APPENDIX A

ETS-1 CALIBRATION SYSTEM

1.0 DESCRIPTION

The ETS-1 Data Acquisition System utilizes three (3) types of electrical system calibration. These are resistive shunt calibration for strain gage bridge channels; resistance substitution for RTT channels; and voltage substitution for swept pot, thermocouple, analog voltage and other active or self-generating transducers. Brief descriptions of these systems are as follows:

1.1 Resistive Shunt Calibration

A six-wire, shunt-calibration system is used (see Figure 1). This system provides two wires exclusive of the bridge excitation and signal leads. These two wires connect a calibration resistor in the signal conditioner across one leg of the strain gage bridge in the transducer. By thus shunting one leg of the transducer bridge, the bridge is resistively unbalanced and a voltage is produced at the transducer output. The calibration resistors are selected to produce 0, 25, 50, and 75% of full scale output signals. In the case of pressure transducers, most transducers are standardized to produce identical outputs at the 25, 50, and 75% calibration steps for one standard set of calibration resistors.

1.2 Resistance Substitution

For RTB's, either a triple bridge or a constant-current potentiometric-type signal conditioner is used (see Figure 9). In either case, calibration is accomplished by substituting precision resistors for the transducer in the signal conditioner, thus simulating the transducer resistance at 0, 25, 50, 75, and 100% of the full scale temperature range. The transducer cannot be left in the circuit for calibration as in the case of strain gages because its resistance varies with the ambient temperature.

1.3 Voltage Substitution

For those transducers such as thermocouples which generate signal voltages without external excitation, voltage substitution calibration is utilized (see Figure 3). These "active" channels are calibrated by substituting voltages

from a precision voltage divider in the signal conditioner for the transducer. This divider provides calibration voltages of 0, 25, 50, 75, and 100% of the full scale channel set-up range. Voltage substitution is also used for swept pot transducers which are not active or self-generating. However, in this case, the transducer and the calibration voltage divider in the signal conditioner are in parallel across the excitation power supply in both the calibration and operational modes. This eliminates the possibility of calibration error caused by different excitation power supply loading during calibration and operation.

2.0 APPLICATION OF ELECTRICAL CALIBRATION

The primary purpose of a system electrical calibration is to measure the effect of channel components on the signal voltage between the transducer or signal conditioner to the end recorder. In other words, as long as we know how many digital counts correspond to a known input voltage for a given channel, the data can be corrected for the channel losses. The system electrical calibration is used to accomplish this correction as described in the following paragraphs.

2.1 The general methods to be employed in reducing Digital Data System (DDS) data acquired from the accuracy study of the ETS-1 data system are:

A simulator traceable to a secondary standard will be employed to simulate various transducers. The output units of the simulator will be described as a range of millivolts (mv) i.e., 0-30 mv, 0-50 mv which can be related to the output of various transducers, such as pressure, temperature, position, etc. The DDS will be ranged to produce 0000-9999 counts full scale output which is proportional to the range that the simulator was set up to produce. With the simulator connected into the DDS system, a standard calibration mode will be executed causing the DDS to sweep each calibration step 64 times and record these values on the DDS magnetic tape. These values are representative of 0%, 25%, 50%, and 75% of full scale output of the DDS and in turn represent that fractional part of the simulator range, i.e., 0-30 mv. These relationships are ideally represented in the following table:

SIMULATOR RANGE 0-30 MV		
(DDS Full Scale Range 0000-9999 Counts)		
<u>% Sense Step</u>	<u>Ideal Counts</u>	<u>mv</u>
0	0000	0.0
25	2500	7.5
50	5000	15.0
75	7500	22.5

In practice, the values are more likely to be as follows:

<u>% Sense Step</u>	<u>Averaged Counts</u>	<u>mv</u>
0	0005	0.0
25	2508	7.5
50	5010	15.0
75	7518	22.5

After calibrating the system, the simulator would be set at some known value (A) within the range previously established (0-30 mv). The DDS would then be operated as under actual test conditions where a series of sweeps or samples would be taken and recorded on the same magnetic tape as the calibrations. The data would appear somewhat as follows:

Let (A) = 15 mv

then the digital output in raw counts would read,

Channel (X)
 5008
 5005
 5007
 5010
 5006
 5009
 etc.

This magnetic tape with its recorded calibrations and parameter(s) constitutes the tape from which the accuracy determination will be made. The conversion of this recorded data into millivolts would proceed as follows:

Using the practical set of calibrations described above, we would derive a zero offset (ZO) and a slope (M) where the $ZO = 1/N \sum$ counts observed for the 0% sense steps and

$$M = \frac{75\% \text{ of Simulator Range (MV)}}{1/N \sum 75\% - 1/N \sum 0\% (\text{Counts})}$$

where $1/N \sum 75\% = \text{Observed Counts for 75\% Sense Steps}$, $N = 64$ and convert raw counts (X) to millivolts according to the formula:

$$\pm MV = \pm M (\pm X \pm ZO)$$

$$\text{i.e.,} \quad 1/N \sum \% \text{ Observed Counts} = \text{Avg ZO} = 0005$$

$$1/N \sum 75\% \text{ Observed Counts} = \text{Avg 75\%} = 7518$$

$$75\% \text{ Simulator Range} = 22.5 \text{ MV}$$

$$M = \frac{22.5}{7518 - 0005} \quad \text{MV/CT} = 0.002995 \text{ MV/CT}$$

$$\text{then,} \quad MV = M (X - ZO)$$

$$= \frac{22.5}{7513} (X - ZO (\text{Avg})) \text{ MV}$$

$$\begin{aligned} \text{where} \quad X &= 5008 \\ &5005 \\ &5007 \\ &5010 \\ &\text{etc.} \end{aligned}$$

$$\text{then,} \quad MV = \frac{22.5}{7513} (5008 - 0005) = 14.984 \text{ MV}$$

$$= \frac{22.5}{7513} (5005 - 0005) = 14.975 \text{ MV}$$

etc.

The determination of system error would employ the following equation where error would be expressed as a % of the point.

$$\% \text{ Error} = \frac{\text{Input MV} - \text{Calc MV}}{\text{Input MV}} \times 100 = \frac{15.0 - 14.984}{15} \times 100 = 0.1066\%$$

APPENDIX B

SIMULATORS

The schematics included herein are the proposed designs of simulators for using during the ETS-1 Data Acquisition Accuracy test program. The simulated input levels for the four types of thermocouples used in the diagnostic channels shall be provided by high quality thermocouple transducers. These transducers shall be dipped in at ice point, molten paraffin, and boiling distilled water point. All simulator and transducers shall have their calibration traceable to the National Bureau of Standards.

Schematics included are:

- Figure 8 - Two-Arm Structural Strain Gage X'ducer Simulator
- Figure 9 - RTT Simulator
- Figure 10 - Swept Pot X'ducer Simulator
- Figure 11 - Four-Arm Structural Strain Gage X'ducer Simulator
- Figure 12 - Four-Arm Strain Gage Simulator

APPENDIX C

DATA ANALYSIS

1.0 GENERAL

Accuracy as used in this report is the difference between the known input and the recorded output stated in terms of a 99% confidence interval such that 99.9% of the data points will fall within the boundaries indicated. The accuracy figures will be stated for two sets of data for each mode of operation defined for the ETS-1 program. One set will consist of the test data obtained after applying the electrical calibration and the second set will be the test data after conversion to engineering units, thus permitting both an ETS-1 data acquisition accuracy and a data processing accuracy value to be obtained. The philosophy inherent in the statistical design and subsequent data analysis is to obtain maximum useful information and to achieve the accuracy objectives with a minimum expense within the schedule requirements of the test program. It is further essential that the data analysis produce results that are valid and applicable to overall analysis of the ETS-1 test program. With these considerations, the test plan was developed to enable error isolation of other factors such as drift, linearity, subsystem variability, or channel-to-channel variability, and to obtain data that will be available for further studies if required. The data results from the Test Cell-A tests and other REON test results have been considered in this program.

The statistical analysis procedure utilizes analysis of variance methods designed specifically to evaluate the objectives of the ETS-1 Data Acquisition System accuracy. To prevent testing at redundant levels or requiring excessive number of channels and/or observations to be evaluated at each mode, preliminary testing will be made as early in the test program as possible. The results of the preliminary test data will enable an optimum number of channels, input levels, drift time increments and repeated observations per test to be determined to yield meaningful data to achieve the desired goals from the tests of the remaining modes.

2.0 DATA ANALYSIS FOR PRIMARY OBJECTIVE

The accuracy for each observation is defined as the difference between the known input and the recorded output. The accuracy of each mode shall be analyzed in terms of a 99% confidence interval which will include 99.9% of the data points. This will be accomplished by computing the system bias and the system standard deviation (noise) where system bias $\bar{X}$ is defined as

$$\bar{X} = \sum_{i=1}^t \frac{(X_i - N)}{t} \quad \text{where } X_i = \text{recorded output}$$

$$N = \text{known input}$$

$$t = \text{number of observations}$$

and system standard deviation (noise), S , is defined as

$$S = \sqrt{\frac{\sum_{i=1}^t [(X_i - N) - \bar{X}]^2}{t - 1}}$$

and the 99% confidence interval for 99.9% of the data points is defined as

$$99\% \text{ confidence interval} = \bar{X} \pm KS$$

where K is a function of the number of observations. Accuracy can be represented schematically as follows:

The above equations are defined assuming that each recorded output is a random sample from a normal population and that factors comprising the accuracy estimate are independent. If these assumptions are not met, statistical modifications in the above definitions will be made to ensure valid and meaningful estimates of accuracy.

2.1 Preliminary Tests Analyses

The data collected and analyzed from the preliminary tests as shown in Table II sheet 1 will permit the following factors to be evaluated concerning their contribution to the ETS-1 Data Acquisition System accuracy. The purpose of this evaluation is to determine the extent of future testing.

- a. System bias
- b. Channel-to-channel variability
- c. Subsystem-to-subsystem variability
- d. Linearity
- e. Drift
- f. Aliasing
- g. Frequency response
- h. Noise

2.1.1 Bias - Bias will be computed using the equation

$$\bar{X} = \sum_{i=1}^t \frac{(X_i - N)}{t} \quad \text{where } X_i = \text{recorded output}$$

N = known input

t = number of observations

for each of the modes.

2.1.2 Channel-to-Channel Variability and Subsystem Variability - Each test defined in Table II will be run on two subsystems using 20 channels per mode, 10 channels for each subsystem, and each channel will yield 64 observations. Modes 16 and 17 run simultaneously and will consist of 20 (5 drift and 4 linearity) tests. Each test will be subjected to the following analyses.

2.1.3 Evaluation of Channel-to-Channel Variability - If the inaccuracy estimate for a given mode is excessive, it is necessary to study the variation of each of the test variables contributing to the inaccuracy. The differences that are observed for each variable are compared to the estimate of noise. If insignificant differences are observed, the variability can be combined or pooled into the error or noise estimate. If significant differences are observed, it is necessary to consider these differences as contributory to the inaccuracy of a mode. Similarly, if the noise estimates are different, statistical methods will be utilized to arrive at a meaningful and realistic estimate of noise.

To illustrate the method of analysis, consider the two subsystems and 10 channels for each subsystem at a given input level and drift time interval. Define S_n^2 as the error mean square or noise estimate caused by the ten channels for one subsystem and S_{cc}^2 as the channel-to-channel mean square for each subsystem where

$$\begin{aligned}
 S_n^2 &= \frac{1}{990} \sum_{m=1}^{100} \sum_{i=1}^{10} (X_{im} - \bar{X}_i)^2 & \begin{array}{l} m = \text{observations} \\ i = \text{channel} \\ j = \text{subsystem} \end{array} \\
 S_{cc}^2 &= \frac{100}{9} \sum_{i=1}^{10} (\bar{X}_i - \bar{X}_j)^2 \\
 \bar{X}_j &= \frac{1}{1000} \sum_{m=1}^{100} \sum_{i=1}^{10} X_{im} \\
 \bar{X}_i &= \frac{1}{100} \sum_{m=1}^{100} X_m
 \end{aligned}$$

A number of comparisons will be made. The ratio of S_{cc}^2/S_n^2 will be evaluated using the F distribution to determine whether or not there is channel-to-channel variation within each of the subsystems. Similar analyses will be made to determine whether S_n^2 and S_{cc}^2 for each of the subsystems can be combined or pooled. If channel-to-channel variability is significant, this variation must be included in the overall accuracy estimate for the mode. The two subsystems will be tested for significance using the pooled estimate as the basis for comparison.

2.1.4 Linearity - Linearity as used in this study will be a comparison of the system bias at different input levels. Thus, if the system bias is the same at each input level, the system is considered linear as compared to the variation about the system bias (noise). The analytical procedure requires determining a least square fit of the data points and comparing any lack of linearity to the noise or random fluctuation of the data by the use of analysis of variance techniques. The primary concern of this analysis is to evaluate linearity in terms of its contribution to inaccuracy. Therefore, the error must be compared to the known input value and not an analysis of recorded output values alone, since a linearly increasing system bias can also contribute to system inaccuracy.

2.1.5 Drift - Modes 16 and 17 will be subjected to 5 time intervals to measure drift. Drift will be evaluated by obtaining the system bias values at each time increment and comparing it to the system bias at 0 time for each level of known input. Thus, drift will be defined as

$$\text{drift} = \frac{\bar{X}_t - \bar{X}_0}{\bar{X}_0} \times 100 \quad \text{Where } \bar{X}_t = \text{system bias at } t \text{ hrs}$$

$$\bar{X}_0 = \text{system bias at } 0 \text{ hrs}$$

2.1.6 Aliasing - The purpose of this analysis is to compute the aliasing error of the ETS-1 Data System as a function of frequency and, also, that caused by inherent system noise. The following data and analyses steps will be made on a specially selected channel which will permit an analysis of the two sampling rates 10 SS low level, and 10 SS high level.

1. One (1) constant amplitude varying frequency signal will be applied. The output amplitude and frequency will be recorded on an oscillograph chart.

2. The ratio of the recorded output amplitude to the known constant input amplitude, A_o/A_i , will be plotted versus input frequency f_i . The half-power frequency, f_1 , will be determined to correspond to $0.707 A_o/A_i$.

3. The input frequency will be plotted versus the output frequency. Aliasing error will be computed only for those frequencies that are less than the channel half-power frequency f_1 and the 0.5x sampling frequency. For these frequencies, compute the aliasing error as follows:

a. For input test frequency f_i define output amplitude A_o and output frequency f_o . Let $A_o = A_2$.

b. Determine the amplitude of a recorded signal which has the frequency, f_o . Call this amplitude A_1 .

c. Compute the aliasing error $\% = A_2/A_1 \times 100$.

4. Plot the aliasing error versus input frequency for each of the four sampling frequencies.

To determine the influence of 60-cycle facility noise on the unfiltered 10 SS low level frequency, record a signal on an oscillograph and into the sampler. Compare the sampled value to the average of the 60-cycle signal. The difference represents the aliasing caused by facility noise.

2.1.7 Frequency Response - A constant amplitude sine wave will be injected on mode 16, Table I of the main part of this report (3 + 4 + 5 + 8) with varying frequencies from 1 cps to 100 kc, recording the signal on wide-band tape and oscillograph recorders. The output-input amplitude ratio will be plotted as a function of frequency to determine the amplitude distortion at high frequencies. It must be emphasized that aliasing and frequency response describe errors of the system only if operated at these frequencies. It is the intent of these preliminary analyses to discover those areas of unacceptable operation.

2.1.8 Noise - Noise is defined as an evaluation of the random fluctuation in signal output about the average of the output (bias). The noise estimates from each test will be combined or "pooled" when proven statistically to be not significant. If the noise estimates are statistically different, an average technique will be developed for combining the noise estimate.

2.1.9 Basis for Selecting Sample Size - A sample size is selected based on three factors; the expected variation (S^2), the precision, and the confidence. For studying the channel-to-channel variation, each subsystem will be evaluated with ten channels. If the two subsystems prove to be the same, the 20 channels will be available for analysis. The 99% confidence interval for 99.9% of the observations is defined by $\bar{X} + KS$ where K is a function of sample size (n) for these requirements. The slope of the K vs n curve is significantly lower at 10 channels and almost constant at 20 channels as illustrated in the table below.

<u>Sample Size Interval</u>	<u>Difference in K, ΔK</u>
$N_i - N_{i+1}$	
3 - 4	18.23
5 - 6	2.46
9 - 10	0.47
14 - 15	0.26
19 - 20	0.09

Thus, it can be seen that 20 channels will be a good estimate of the prescribed accuracy.

3.0 DATA ANALYSIS FOR SECONDARY OBJECTIVES

The analysis described herein for secondary analysis pertains to studies and analyses that are desirable to support the ETS-1 Test Program although the results may not pertain directly to the accuracy estimate for the ETS-1 Data Acquisition System. The analysis will be performed only where end-to-end modal accuracy indicates such analysis is essential.

3.1 Calibration Analysis

The primary task for the calibration analysis is to assess the estimate of noise as compared to the more accurate simulated signal. Data shall be collected to enable the following studies to be made:

1. Evaluation of noise at each input level from the signal conditioner (calibration) to be compared by statistical methods to an evaluation of the noise from the simulated signal of the test program. The analysis will consist of pooling the data when appropriate and using the F distribution for comparing the two sets of data.
2. Evaluation of variations of the averages from the five signal input levels for the calibration procedure compared to the variation observed from the four signal levels of the test program for a given mode. Analyses of variance methods shall be used to assess whether input levels indicate significant variational patterns.
3. Evaluate an index of linearity for the calibration runs and compare to each of the related test runs. The concept of linearity will be explicitly defined in terms of the ETS-1 hardware and conversion procedures.
4. Evaluate the conversion coefficients for converting Binary Coded Decimal (BCD) units to raw data by several methods such as the least square method, centroid method, polygon method and two-point method.

5. Evaluate the variability that can result in the engineering measurement for the estimation of each of the conversion coefficients when different systematic errors are introduced, i.e., drift, curvilinearity, or random deviations from predicted.

3.2 Crosstalk

The tested modes for dc and ac will be evaluated for the influence of cross-talk. For dc signals, ten channels for each of five input levels will be evaluated by examining the unstimulated channels adjacent to a stimulated channel. The channel with the maximum cross-talk indications will be used for the analysis. Alternating current cross-talk will be analyzed in a similar manner, but with a sinusoidal input signal. One-hundred observations will be observed for each level of input so averages and standard deviations will be compared. Thus 50 averages and standard deviations will be available for each dc signal and 40 averages and standard deviations will be available for ac signals. The data is being collected to be descriptive in nature although provision can be made to expand cross-talk analysis into an experimental design to study other factors or levels of operation.

3.3 Drift and Linearity

Data taken for drift and linearity measurement will be utilized for estimating components of the total inaccuracy variation, if such a study is proved necessary for analysis of variance technique. Most of the analysis will be performed with the preliminary test data. Table II (in the body of the text) outlines the proposed test program.

3.4 Application of Preliminary Test Analysis to Overall Test Program

Based on the analysis of the preliminary test program, the following recommendations will be made and action taken for the remaining modes of the test program.

(a) A final number of subsystems, levels, times and channels required to determine the accuracy to a desired index of system precision and confidence will be ascertained.

(b) The number of observations per channel required to estimate noise will be established.

(c) If the levels, times, channels, or subsystem prove to be significant, appropriate analysis procedures will be formulated. If large differences are detected in some portion of the system, additional data acquisition may be recommended.

(d) A data processing program will be prepared for the remainder of the modes.

(e) System limitations as determined by the aliasing and frequency response tests will be presented.

3.5 Mode-to-Mode Variation

Each mode will have an accuracy estimate as well as a 99% confidence interval regarding 99.9% of the observations. Since many modes contain overlapping paths, the difference between segments of the paths can be evaluated. For example, if one mode differs from another mode by inserting mechanisms for recording data, the influence of the added signal path can be isolated and an estimate made of the accuracy of the added segment of signal path. Variation in modes utilizing narrow or wide band amplifiers can be assessed as well as the influence of different sampling rates in the digitizer.

TABLE I OPERATIONAL TEST MODES

Mode No.	Modes	Fig. No.	Channel Type	Range Card No.	Range	No. Simulated Inputs	10 S.S. Low Level	10 S.S. High Level	50 S.S. High Level	100 S.S. High Level	Strip Chart Recorder	Magnetic Tape Recorder	Oscillo-graph Recorder	Narrow Band Amplifier	Wide Band Amplifier
1	2+3	2	Thermocouple C/A	Th02	32°F to 251°F	2			x		x			x	
2	1	2	"	Th04	32°F to 475°F	2	x								
3	2	2	"	Th05	0°F to 506°F	2			x					x	
4	2+3	2	Thermocouple C/C	Th06	-212°F to 266°F	2			x		x			x	
5	1	2	"	Th06	-212°F to 266°F	2	x								
6	2	2	"	Th06	-212°F to 266°F	2			x					x	
7	2+3	2	Thermocouple W/WRE	Th13	+32°F to 4500°F	2			x		x			x	
8	1	2	"	Th13	+32°F to 4500°F	2	x								
9	2	2	"	Th13	+32°F to 4500°F	2			x					x	
10	2+3	2	Thermocouple WRE/WRE	Th12	+32°F to 4500°F	2			x		x			x	
11	1	2	"	Th12	+32°F to 4500°F	2	x								
12	2	2	"	Th12	+32°F to 4500°F	2			x					x	
13	1	3	4 Arm Strain Gage 350 OHMS	SG04	Standard	4	x			x					
14	2	3	"	SG04	Standard	4		x						x	
15	3+5+6+8	3	"	SG04	Standard	4			x		x	x			x
16	3+4+5+8	3	"	SG04	Standard	4				x		x	x		x
17	7+8	3	"	SG04	Standard	4			x					x	
18	3+4+8	3	4 Arm Strain Gage 120 OHMS	SG06	Standard	9			x				x		x
19	3+8	3	4 Arm Strain Gage 60 OHMS	SG07	Standard	9			x						x
20	1	4	2 Arm Strain Gage 120 OHMS	SG01	± 3K in.	7			x						x
21	1+2	4	"	SG01	± 3K in.	7		x			x				x
22	1	5	RTT		-425°F to -400°F	2		x						x	
23	2	5	RTT		-425°F to -400°F	6	x								
24	1	6	Swept Pot	SP01		4			x						
25	2	7	Analog Voltage	AV01		% F.S.			x						x
26	2+3	7	Analog Voltage	AV01		% F.S.			x		x				x

TABLE II - SHEET I

Mode No.	Calibration No.	Time Hrs.	PRELIMINARY TEST MODES							
			SIMULATED INPUT LEVELS							
			0%	25%	50%	75%	ice pt.	boil H ₂ O	lead pt.	REMARKS
16	1a	0	x	x	x	x				
		0+2	x	x	x	x				
		0+4	x	x	x	x				
		0+8	x	x	x	x				
		0+12	x	x	x	x				
	1b									
17	2	0	x	x	x	x				
13	4									D.C. Crosstalk
16										A.C. Crosstalk
16										Frequency Response
Spec										Aliasing

Note: Each x above includes the samples per paragraph 4.3.1 Preliminary Tests and as listed in tabular form in Appendix C paragraph 2.1 Preliminary Test Analyses. The x refers to tests made on 10 channels in each of 2 subsystems with 100 readings (samples) taken per channel. Each x is equivalent to 2000 samples.

TABLE II - SHEET 2

Mode No.	Calibration No.	Time Hrs.	PROGRAM TEST MODES							REMARKS
			SIMULATED INPUT LEVELS							
			0%	25%	50%	75%	ice pt.	boil H ₂ O	lead pt.	
19	5a	0	x	x	x	x				
		0+2	x	x	x	x				
		0+4	x	x	x	x				
		0+8	x	x	x	x				
		0+12	x	x	x	x				
	5b									
13	6	0	x	x	x	x				
14	7	0	x	x	x	x				
15	8	0	x	x	x	x				
18	9	0	x	x	x	x				
1	10	0					x	x		
2	11	0					x	x		
3	12	0					x	x		
4	13	0					x	x		
6	14	0					x	x		
7	15	0					x	x		
8	16	0					x		x	
9	17	0					x		x	
10	18	0					x		x	
11	19	0					x		x	
12	20	0					x		x	
20	21		x	x	x	x				
21	22		x	x	x	x				
22	23		x	x	x	x				
23	24		x	x	x	x				
24	25		x	x	x	x				
25	26		x	x	x	x				
26	27		x	x	x	x				
5	28	0					x	x		
		0+2					x	x		
		0+4					x	x		
		0+8					x	x		
		0+12					x	x

Figure 1

ETS-1 X-Engine Digital Data System

Figure 2

Thermocouples - C/A, C/C, W/WRE, WRE/WRE

* PER TABLE 1 COLUMNS 1 & 2

Figure 3
Four-Arm Strain Gage Bridge, 350 , 120 , 60
48

* PER TABLE I COLUMNS 1 & 2

Figure 4

Two-Arm Strain Gage Bridge 120

Figure 5
Resistance Temperature Bridge (RTB)
50

* PER TABLE 1 COLUMNS 1 & 2

* DATA MODE
2 4 | 1 ALONE (50 SS)

* PER TABLE I COLUMNS 1 & 2

Figure 6
Swept Potentiometer
51

DATA MODES

*		
2 5		2 ALONE (50 SS)
2 6		2 + 3

* PER TABLE I COLUMNS 1 & 2

Figure 7
Analog Voltage 0-5 Volts
52

$$\text{Gage Factor} = 2 = \frac{dR/R}{dl/l}$$

$$R_{si} = \frac{1.02R (1 + 2 dl/l)}{2 (0.01 - dl/l)}$$

$$R_{si} \leq R_{si} \leq R_{s21}$$

$$-10^{-2} \frac{\text{in}}{\text{in}} \text{ (Compression)} \leq dl/l \leq +10^{-2} \frac{\text{in}}{\text{in}} \text{ (Tension)}$$

$$R_{si} = \infty \therefore R_o = 1.02 R$$

Calibration of Simulator;

$$\frac{V_{B - F, c}}{V_{A, E - F, c}} \quad \text{vs the 21 Switch Positions}$$

Figure 8

Two-Arm Structural Strain Gage X'ducer Simulator

Resistors are all $\pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$, 1/2 W with four terminals

R-1 = 1736.60 Ω

R-2 = 1380.00 Ω

R-3 = 814.94 Ω

R-4 = 328.25 Ω

R-5 = 33.212 Ω

R-6 = 5.584 Ω

S-1 Daven 142-DB-6

J-1 Micro- 058-0006 235774

Dott

Figure 9

RTT Simulator

* 1%, 5 PPM/C° ~ All others 0.05%, 5 PPM/C°

Calibration of Simulator;

$$\frac{V_{F - B, C}}{V_{A, E - B, C}} \text{ vs } 0\%, 25\% \dots 100\% \text{ Switch Position}$$

Figure 10
Swept Pot X'ducer Simulator

Figure 11

Bridge trim resistors (R-9 & R-10)

Bridge trim resistor (BT) value to be determined for each individual CCT to trim in each bridge. Make from No. 28 Manganium Wire.

Resistor Values:

- R-1 = $27,910 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-2 = $37,280 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-3 = $56,000 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-4 = $112,200 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-5 thru R-8 = $350 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-9 = $10,000 \Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$
- R-10 = 20 Ω Potentiometer,

Daystrom 200-66, 20 Ω

Daystrom Incorporated, Potentiometer Division
Archbald, Pennsylvania

Switch S-1, L & N

Figure 12